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Convection in vertical Bridgman configurations

by

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Vertical Bridgman growth of compound semiconductors is associated with natural convection. The natural convection is of two types viz: buoyancy driven and surface tension gradient driven. The former (Rayleigh) is of importance under earth's gravity and may be due to adverse temperature or solutal gradients in the liquid melt. Surface tension gradient or Marangoni convection is important when we have liquid encapsulated Bridgman growth. In this configuration a viscous but lighter fluid overlies the melt of the compound semi-conductor in question. This provides a suitable diffusion barrier of volatile constituents but in the process an interface between the liquids is formed and this in turn can generate convection. This convective phenomenon arises because of surface tension gradients that are promoted through a potential such as temperature or concentration gradients. We are interested in tracing the convective profiles in two configurations- these are the pure Rayleigh convective mode and the combined Rayleigh - Marangoni mode. In order to do so we conducted a numerical investigation that involved a 'finite volume' calculation. The governing equations were integrated about a cell volume, using the Gauss Theorem and the volume variables like temperature and velocity were related to the surface variables. In order to solve for the pressure field we employed the continuity equation and the residuals resulted in a Poisson equation. The results and comments for the Rayleigh and Marangoni problems in a vertical cylinder or Bridgman configuration were as follows:

- a) Three- dimensional and two- dimensional disturbances on the three dimensional equations were examined. The steady solutions converged to two- dimensional axisymmetric motion for cylinders that had an aspect ratio of unity or less (aspect ratio is defined as height/radius). The flows were three dimensional for aspect ratios greater than unity.
- b) The results were compared to those of Neumann (1990). The total energy of the flow was computed as a function of problem time. It was observed that the energy reached a steady state much sooner than the individual velocity components. The criterion for convergence used by Neumann is therefore suspect.
- c) The calculations were repeated for the pure Marangoni problem and the results of Vrentas, Narayanan and Agrawal (1981) were verified.

On a separate level, linearized stability calculations for the onset conditions for Rayleigh - Marangoni in a laterally unconstrained bilayer were performed and the results are given below:

- a) Liquid bilayers heated from above become more stable as the gravitational level is increased. As a result bottom- seeded crystal growth is better performed on earth.

b) Liquid bilayers that are heated from below become more stable as the gravitational level is decreased.

c) The above results will change for narrow geometries and so this raises the important question on what effect side walls will have on the stability of the flow.

References:

1) Neumann, G., "Three-dimensional numerical simulation of buoyancy-driven convection in vertical cylinders heated from below.", *J. Fluid. Mech.* (1990), **214**, pp 559-578

2) Vrentas J.S., Narayanan R. and Agrawal S.S., "Free surface convection in a bounded cylindrical geometry", *Int. J. heat and Mass Transfer*, **24**, (1981), pp. 1513-1529